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Willingness to Pay for Water Quality Improvements: The Case of Precision Application Technology

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A contingent valuation survey conducted in Mississippi is used to assess public willingness to pay for reductions in agricultural nonpoint pollution. The analysis focuses on implementation of a policy to provide farmers with precision application equipment to reduce nutrient runoff. Findings suggest public support exists for such policies. This study also finds that inclusion of debriefing questions can be used to refine willingness-to-pay estimates in contingent valuation studies. A nonparametric scope test suggests respondents are sensitive to level of runoff reduction and associated water-quality benefits.

Key words: contingent valuation, econometrics, site-specific management, variable-rate technology

Introduction

In recent years, public concern about potential environmental damages has spurred development of environmentally friendly agricultural practices and technologies. New water quality rules in the form of total maximum daily load (TMDL) standards for watersheds will intensify regulatory attention on agricultural practices. Thus, new practices and technologies aimed at reducing agricultural nonpoint pollution will be needed for producers to meet water quality standards. One technology that holds promise for reducing runoff is variable-rate technology (VRT), which precisely matches nutrient and chemical application to local crop needs.

A contingent valuation (CV) survey was conducted in Mississippi to measure public willingness to subsidize the adoption of VRT to mitigate agricultural pollution. A survey of the public in Mississippi is of particular interest because the state is critically located within the lower Mississippi River Basin, and has a high percentage of rivers and streams on the U.S. Environmental Protection Agency's (USEPA's) 301(D) list of impaired waterways (USEPA 1998).

Additionally, in 1999, the National Oceanic and Atmospheric Administration (NOAA) issued a set of reports on the hypoxic, or "dead," zone[1] in the Gulf of Mexico to the White

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[1] The Gulf of Mexico hypoxic zone is an area about the size of Massachusetts where oxygen levels are below those necessary to sustain most animal life. The quality of sports and commercial fisheries is adversely affected by hypoxia.

House Committee on Environment and Natural Resources. The NOAA reports link the size of the dead zone to influx of nutrients, primarily originating from agricultural runoff.[2] Based on a cost-benefit analysis, Doering et al. suggest that among the most economically efficient means of controlling hypoxia would be to restore wetlands and riparian zones in a number of geographic areas, with the Delta region of Mississippi being heavily targeted. Even though the state's net outflows of nitrogen into the basin are lower than those of Corn Belt states, Mississippi may contribute more to hypoxia because of its proximity to the Gulf of Mexico.

A contingent valuation study in Mississippi is also of interest because Mississippi shares a number of attributes with other states in the Midsouth. In particular, its economy is dominated by agriculture, and it is among the poorest states in the United States. Further, issues associated with TMDLs have received significant publicity in recent years, and there is public concern about the impact of environmental regulations on the state's economy.

This contingent valuation study was designed to measure Mississippi taxpayers' willingness to pay (WTP) for a subsidy to producers that provides public benefits.[3] Citizens who believe adoption of variable-rate technology would reduce agricultural pollution of fresh water, and who value environmental quality in the form of clean water, should be willing to pay for a program to subsidize adoption of the technology. Public perceptions of agriculturally related nonpoint pollution are assessed, and public willingness to pay for a program to adopt precision application technology to improve water quality is estimated in this analysis.

Importance of Reducing Nonpoint Water Pollution

Since implementation of the 1972 Clean Water Act, point source pollution has been significantly reduced, but nonpoint pollution remains a problem, particularly runoff of chemicals and nutrients into bodies of water. Based on USEPA (1998) findings, nationally over one-third of streams, lakes, rivers, and estuaries surveyed in 1996 did not fully support their designated uses, with nonpoint pollution cited as the major cause.[4] Agriculture is alleged to be the largest contributor to nonpoint pollution because farmers have intensified their use of agricultural chemicals over the past 50 years, leading to increased runoff of herbicides, pesticides, sediment, and nutrients.

Water quality degradation attributable to agricultural pollution is costly in terms of surface water damages (Lichtenberg and Lessley) and drinking water treatment (Forster, Bardos, and Southgate; Murray and Forster). Franco, Schad, and Cady cite nitrate removal costs within one California district of approximately $375 per million gallons. Given that USEPA (1999) reports annual average *total* treatment costs for the United States at $300 per million gallons, the costs of nitrate removal alone can be significant. Thus, developing ways to decrease agricultural runoff to meet federal clean water standards is an important public policy concern.

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[2] Model results from NOAA suggest reductions of 20–30% in nutrient loads would result in 3–15% reductions in surface chlorophyll concentrations and 15–50% increases in bottom-water dissolved oxygen concentrations in the hypoxic zone.

[3] However, because of the scope of the problem, the hypothetical program proposed in this study was framed from a national perspective—i.e., the survey participants were told the program would benefit all U.S. farmers and be paid for by all U.S. citizens.

[4] Nonpoint pollution also has a substantial impact on groundwater degradation in parts of the United States. However, groundwater contamination is not a major issue in Mississippi because of the state's geological characteristics.

Four policies have been used to combat agricultural pollution: voluntary education and technical assistance programs, subsidy programs to promote adoption of conservation practices, regulation of pesticides, and use of compliance mechanisms (Ervin). By the very nature of nonpoint pollution, however, it is difficult to implement and monitor reduction programs because of the large number of sources (Cabe and Herriges). To date, education has been the primary method used to encourage reduction of agricultural nonpoint pollution by promoting altruistic behavior and stewardship among agricultural producers (Ervin; Ribaudo and Horan).

Because environmental stewardship is driven by personal attitudes, it is important to understand the motivations of agricultural producers. Several studies suggest producers will not fully participate in voluntary programs for nonpoint pollution reduction, underscoring the relevance of the research presented here. In general, findings indicate individual farmers tend not to recognize their own contribution to nonpoint pollution, and would resist direct limitations on nonpoint pollution, but would be willing to increase runoff controls under cost-sharing programs (Lichtenberg and Lessley; Pease and Bosch; Napier and Brown). Results obtained by Bosch, Cook, and Fuglie show regulation is more effective than education in inducing adoption of site-specific management practices.

One possible strategy to reduce nonpoint pollution is the adoption of techniques such as variable-rate technology (VRT) and site-specific management. These technologies have shown some promise in reducing runoff of agricultural chemicals, thereby decreasing nonpoint pollution (Oriade et al.; Schnitkey and Hopkins; Hite, Hudson, and Intarapapong). Although VRT may provide environmental benefits, producers would be generally reluctant to adopt a technology having a certain, large fixed cost for equipment but uncertain future profits. The results of studies comparing profitability of VRT and conventional application techniques have been mixed (e.g., Blackmore et al.; Carr et al.; Sawyer). In an analysis of site-specific farming, Swinton and Lowenberg-DeBoer found that revenues increased under VRT by about 7.2%, mostly from quality improvements. A public program to help producers defray fixed-cost investments in equipment may be needed to promote VRT adoption (Isik, Khanna, and Winter-Nelson). These findings provide impetus for the examination of a cost-share program such as the one investigated in this study.

Survey Design and Instrument

The survey was devised as a single-price referendum CV instrument in which two questions were examined: (*a*) public perceptions about agricultural impacts on the environment, and (*b*) how perceptions may influence willingness to pay a one-time tax to subsidize agricultural producers' costs of purchasing VRT equipment. The survey instrument was based on a format using follow-up debriefing questions. The sample frame was limited to members of the voting-age public in Mississippi. A telephone survey was chosen as the means of administration because previous mail surveys in Mississippi have resulted in extremely low response rates. A pretest of the survey was conducted to test the survey instrument and econometric methods.

The central goal of the survey instrument was to establish the perceived water quality benefits of the proposed program. Because expected improvements in water quality depend on weather conditions and soil erodibility, among many other factors, it is difficult to link runoff reduction with a specific measure of water quality improvement.

In the survey instrument, reductions in chemical, nutrient, and sediment runoff were assumed to improve water quality.

Measuring public awareness of agricultural nonpoint pollution in a survey is difficult. Explaining the benefits of reducing nonpoint pollution in a way that could be understood by respondents in a phone survey was equally challenging. In order to determine whether benefits of the program were well understood, a scope test using two levels of runoff reduction was employed.

Measures of the impacts of VRT adoption, based on Mississippi data, were included in the survey. With no previous studies to use as guides, reduction in nonpoint pollution was calculated by simulation using the Erosion/Productivity Impact Calculator, or EPIC (Sharpley and Williams).[5] To obtain estimates of nonpoint pollution reduction from VRT, a hypothetical farm representative of soil types, topography, and weather in the Mississippi Delta (Intarapapong) was developed. Using EPIC and the representative farm data, simulated runoff was calculated under single- and variable-input application rates, based on continuous cotton, corn, and soybeans with conventional tillage.[6] Nitrogen fertilizer, insecticides, and herbicides were the inputs of interest, and the combined runoff of sediment, nutrients, pesticides, and herbicides was the output of interest. Simulation results suggest gross runoff under VRT would be approximately 10% below that of the single-rate application. Thus, in the survey, the baseline environmental benefit of precision application technology was assumed to be a 10% reduction in nonpoint pollution.

The survey included questions ranking government spending programs (e.g., public assistance, and crime fighting), questions about perceptions of agricultural nonpoint pollution (beliefs, concerns, awareness, and knowledge), and questions about participation in recreational activities at or near freshwater lakes, streams, or rivers. Household socioeconomic and demographic information was also elicited.

To provide a framework for the valuation question, respondents were informed about current water quality in Mississippi. Because the survey was conducted by telephone, water quality information was imparted through a series of short questions regarding a respondent's knowledge of water quality facts. For these questions, information was used about the degree to which surveyed bodies of water in Mississippi met designated uses (USEPA 1998). A typical question was:

> Are you aware that 94% of tested rivers [in Mississippi] have fair and partially supporting water quality? This means that the waters support a limited number of fish species and occasionally the water quality interferes with human activities in or near the water.

Eight versions of the survey instrument were developed, based on a factorial design of four prices and two levels of nonpoint pollution reduction.[7] The baseline 10% reduction in nonpoint pollution was obtained from the simulation model, while a 20% reduction was used to formulate a statistical scope test of the robustness of the survey instrument design. Respondents were asked to vote for a bid-runoff pair consisting of a one-time tax

[5] EPIC simulates biophysical systems processes over long periods of time, based on soil, climate, and cropping practices. Outputs of the model include crop yields and edge-of-field environmental parameters associated with various agricultural practices.

[6] The single rates used in this study were obtained from producers' planning budgets of major crops in the Delta, Mississippi's primary agricultural production region. Prescription variable application rates for different soil types and conditions were obtained through consultation with an expert on soil chemistry from the Plant and Soil Science Department, Mississippi State University (Oldham; details are available from the authors on request).

[7] The survey instrument is available from the authors on request.

payment and a runoff reduction percentage (e.g., $50 tax and 10% runoff reduction, $50 tax and 20% runoff reduction, etc.). Respondents were told the program would be nationally implemented, and the tax would be added to their federal tax return the following year.[8]

To obtain a realistic tax payment figure, the cost of precision agricultural application equipment was calculated based on three prices—$10,000, $15,000, and $20,000 per equipment package—for all farms in the United States.[9] The total number of VRT packages required to implement the program in the United States was calculated to arrive at the total cost of the program under each of the three price scenarios.[10] The resulting cost was then divided by the number of individual tax returns filed in the United States in 1998. A one-time tax price for the program was estimated to range from approximately $27 to $76 per taxpayer, providing a basis for the referendum prices used in the survey ($25, $50, $100, and $150).[11]

Referendum CV as used here has been the preferred format to elicit WTP for public programs since publication of the NOAA Blue Ribbon Panel report on contingent valuation (Arrow et al.). In addition, Carson, Flores, and Meade, and Carson, Groves, and Machina demonstrate that single-price CV minimizes incentive incompatibility, thereby reducing strategic behavior. To improve estimates, the Blue Ribbon Panel proposed the inclusion of a "Don't Know" response to provide more information about WTP, but studies following such a design have had mixed results. Carson et al. concluded that most survey participants who would respond to the "Don't Know" category would most likely vote against the program and should be coded as "No" vote respondents. Findings from a split-sample study by Champ, Alberini, and Correas suggest a model including a "Don't Know" category (as in Wang) is not statistically superior to the standard discrete choice model. In this study, the convention of coding "Don't Know" as a "No" vote was followed.

Although explicitly modeling "Don't Know" increases the number of censoring intervals, which should improve estimates of willingness to pay, WTP remains fully censored. As an alternative to a "Don't Know" category, a follow-up question was included in the survey used in this study. In the follow-up question, all "No" and "Don't Know" vote respondents were asked if they would pay any positive amount for the program. This follow-up question therefore elicits noncensored responses from those not willing to pay anything, and should improve precision of econometric estimates.

The survey was administered by trained enumerators using random-digit dialing of Mississippi residents at the Telephone Survey Unit, Social Sciences Research Center, Mississippi State University, during the first two weeks of July 1999. A pretest of

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[8] Because the program was assumed to be implemented nationally, federal tax returns were used as the payment vehicle. It is a shortcoming of the instrument design that we did not clarify to individuals receiving federal tax refunds that the program would reduce the amount refunded.

[9] These price levels were obtained from GPS, Inc., Inverness, MS, for three different packages of equipment. Price differences were a result of different levels of sophistication of GPS receivers, computer hardware, and VRT controllers.

[10] It was assumed one sprayer could effectively service 1,000 crop acres, and would be used to cover those 1,000 acres three to five times a year. Total cropland acreage in the United States was then divided by 1,000 to arrive at the necessary number of VRT packages, which was then multiplied by the assumed price per package. The program was assumed to be a one-time subsidy to speed the rate of adoption of technology, and as such, equipment depreciation was not taken into account in the calculation of the tax payment.

[11] It is a fairly common practice in CV surveys to obtain bid vectors from focus groups or pretesting. In this case, we had the advantage of knowing a target tax price (not unlike a school levy referendum, for example) which could be used to obtain a bid vector.

approximately 10 randomly dialed respondents was used to evaluate respondents' understanding of questions. To ensure a random sample of adults 18 years of age or older in a household, respondents were limited to the adult who had most recently observed a birthday (i.e., day and month) at the time the survey was administered. Of 1,048 total eligible respondents, 828 completed the interview, representing a 79% completion rate.

Survey Results

The sample is comprised of 65.8% white and 29.8% black respondents, whereas the U.S. Census estimates for Mississippi's voting age population in 1999 were 65.7% white and 33.3% black. The average age of survey respondents is 45.4 years, compared with the Census estimate of 45.3 as the average voting populace age. Thus, the sample represents population age and race quite well, with blacks slightly underrepresented. Classifying by respondents' place of residence, the sample consists of 8.6% farm or ranch respondents, 41.9% nonfarm rural respondents, and 46.5% urban respondents.

In general, respondents ranked government spending on environmental programs fairly low, behind such programs as highway improvement, public education, crime prevention, and health care. However, about 45% of respondents felt too little was spent on preventing air and water pollution, suggesting some concern for environmental issues.

Statistics regarding respondents' beliefs and attitudes about pollution are presented in table 1. Respondents exhibited little awareness of agriculture's contribution to nonpoint pollution. When asked to name which one or two sources were believed to contribute most to nonpoint pollution, agricultural runoff from livestock was the second least mentioned (9.4%), and agricultural runoff from crops was the third least mentioned (14.6%). However, most respondents believed agricultural pollution reduces biodiversity (69.2%), and a clear majority felt that a national goal of protecting nature and preventing pollution would be at least a somewhat important national goal. Finally, most respondents agreed technology could be used in ways which are beneficial to the environment while maintaining or increasing standards of living.

Of the 828 total respondents, 62.4% voted for the program to promote precision application technology, and 24.3% voted against the program; 1.3.% of respondents voted "Don't Know," and were subsequently coded as "No" votes for the econometric analysis. As reported in table 2, the highest-ranked reason for a "Yes" vote is to protect the environment for human health (81.4%), and the second highest-ranked reason is to help farmers (7.74%). The most common reason given for a "No" vote is "we already pay too much in taxes" (45.8%).

Scope Test and Econometric Analysis

Before proceeding with the econometric analysis, a nonparametric scope test was employed to detect so-called part-whole bias that results from a variety of sources, particularly improper specification of program benefits. Part-whole bias arises when respondents value a larger or smaller entity than intended by the researcher (Mitchell and Carson, p. 237). In the context of the current study, part-whole bias would occur if program benefits were misspecified and respondents then voted for the reduction of nonpoint pollution regardless of the amount of reduction offered by the program.

Table 1. Survey Responses Concerning Beliefs and Attitudes About Nonpoint Pollution (N = 828)

Survey Question	Percent Response
1 What do you believe is the primary cause of nonpoint pollution?[a]	
▸ Discharge of factory waste	51.3
▸ Sewage from cities and towns	41.9
▸ Leaking garbage dumps	39.4
▸ Agricultural runoff from crops	14.6
▸ Agricultural runoff from livestock	9.4
▸ Runoff from roads and highways	8.8
2 Is a national goal of protecting nature and preventing pollution . . .	
▸ Very important?	58.8
▸ Somewhat important?	36.8
▸ Not at all important?	3.5
3 Can technology be used to achieve a cleaner environment while promoting an increasingly good standard of living?	
▸ Agree	80.2
▸ Neutral	10.0
▸ Disagree	4.6
4 Do you believe that agricultural pollution causes reduced biodiversity?	
▸ Yes	69.2
▸ No	18.7

[a] For question #1, respondents could list two choices.

Table 2. Respondents' Reasons for "Yes" and "No" Votes to Question on WTP for Program to Promote Precision Application Technology (N = 828)

Respondents' Reasons for Voting "Yes" or "No"	Percent Response
"YES" Votes (= 62.4%):	
▸ To protect the environment for human health	81.4
▸ To help farmers	7.7
▸ The cost of the program is low compared to the benefits	3.9
▸ To protect the environment for biodiversity	2.7
▸ To protect the environment for uses like hunting and fishing	2.1
▸ To protect the environment for uses like swimming and boating	0.2
▸ None of these; some other reason	1.2
▸ Don't know	0.8
"NO" Votes (= 24.3%):	
▸ We already pay too much in taxes	45.8
▸ I don't want government involvement	15.9
▸ I don't believe the program will help the environment	14.9
▸ The program costs too much	9.4
▸ None of these; some other reason	13.4
▸ Don't know	0.5

Because the survey was administered via telephone, scope was of particular concern. Researchers have identified a number of reasons for scope failure, and telephone surveys that do not provide visual inputs to the survey process have been considered suspect in some cases (see, for example, McFadden). Other researchers, such as Whitehead, Haab, and Huang, have concluded it is possible to measure scope effects in telephone surveys with a properly designed survey instrument. The following test results provide further evidence to show scope can be detected in telephone surveys.

The abatement level (or nonpoint pollution reduction) variable (*ABATE_LVL*) provides a basis for an external scope test.[12] Initial tests are based on differences in nonparametric estimates of mean WTP calculated from the Kaplan-Meier estimator (Mead) to validate respondent understanding of potential water quality benefits. The tests are based on univariate analysis of the response to the WTP question, where "Yes" votes were coded as 1, and "No" and "Don't Know" votes were coded as 0. The responses from different survey versions were then pooled to determine the proportion of respondents in each version with WTP greater than the tax prices.[13] If respondents are consistent in demonstrating higher WTP for 20% as opposed to 10% abatement levels from the nonparametric means, then the difference between estimated WTP should be significantly different.

Table 3 presents the results of univariate nonparametric estimates based on the response to the WTP question. Respondents at all price levels were randomly assigned 10% and 20% abatement levels, and the data were then segmented into subsamples according to the two levels. Following Hosmer and Lemeshow (pp. 53–60), nonparametric estimates of means and variances of WTP for each subsample were used to calculate a log-rank test of the difference in distribution of means. In the test of response to the WTP question, the mean estimate is $46.97 for the 10% abatement level and $49.94 for the 20% abatement level. The null hypothesis is that there is no difference in distribution of mean WTP for different abatement levels versus the alternative that WTP for 20% abatement is significantly greater than WTP for 10% abatement. The value of the log-rank statistic suggests the difference in distribution of means (i.e., difference in mean at each price level) is significant at the 99% level ($\chi^2_{[1]} = 48.46$).

It is important to note the *ABATE_LVL* variable is derived from background information prefacing the WTP question:

> Next, we want your opinion on a new program that reduces agriculturally related nonpoint source pollution. This program uses a new technology, which would require individual farmers to make a significant investment in new farm equipment. The equipment would reduce chemicals such as fertilizers and pesticides applied on crops. As a result, nonpoint source pollution going into streams, lakes, and rivers should decrease over time.
>
> By using this new technology, scientists predict a XX% [where XX% is randomly assigned to be 10% or 20%] decrease in total chemical runoff. Because these predictions are uncertain, in the near future the program may realistically only prevent water bodies from becoming more polluted.

[12] An external scope test, as defined by Carson, Flores, and Meade, is based on split samples with a different benefit level posed to each sample.

[13] The observations from the different questionnaire versions can be pooled because the samples were randomly selected. It is then assumed that any respondent who received a questionnaire with a tax price of $50 and who exhibited $WTP > \$50$ would also have $WTP > \$25$.

Table 3. Kaplan-Meier Nonparametric Estimates of Mean WTP (N = 828)

POOLED SAMPLE

Price	No. $WTP \geq Price$[a]	$\Pr(WTP \geq Price)$
$0	828	1.00
$25	517	0.62
$50	380	0.46
$100	241	0.29
$150	113	0.14

Mean WTP = $48.46, Variance WTP = 3.37

SUBSAMPLE: 10% Abatement Level

Price	No. $WTP \geq Price$[a]	$\Pr(WTP \geq Price)$
$0	412	1.00
$25	253	0.61
$50	183	0.44
$100	115	0.28
$150	54	0.13

Mean WTP = $46.97, Variance WTP = 6.67

SUBSAMPLE: 20% Abatement Level

Price	No. $WTP \geq Price$[a]	$\Pr(WTP \geq Price)$
$0	416	1.00
$25	264	0.63
$50	197	0.47
$100	126	0.30
$150	59	0.14

Mean WTP = $49.94, Variance WTP = 6.83

Log-Rank Test: $\chi^2_{[1]} = 48.46$

Note: The number of respondents to each questionnaire version are as follows: $25, 10% = 104; $25, 20% = 105; $50, 10% = 104; $50, 20% = 104; $100, 10% = 101; $100, 20% = 104; $150, 10% = 103; $150, 20% = 105.

[a]No. $WTP \geq Price$ represents the total number of "Yes" votes over all questionnaire price levels (c.f. text footnote 13).

There are two ways in which the above description could be interpreted by respondents. First, respondents might believe the runoff reductions will actually improve water quality by some unknown amount. Or second, they may believe the program will provide no improvement in water quality. If a subset of respondents interprets the statement to mean there will be no program benefit, then there should be no sensitivity to scope among that group. The fact that WTP estimated from the nonparametric mean passes the scope test implies the proportion of residents who believed the program would provide benefits was greater than the proportion who did not. This finding suggests the survey was successful in explaining the program benefits of incremental water quality improvement to most respondents.

The econometric analysis employs a first-price probit model that censors WTP at threshold values, but allows for uncensored values for individuals who state a zero WTP on the follow-up question. Because the survey used a hypothetical tax referendum format, we have only the information that $WTP_i \geq \tau_j$ for individuals who vote "Yes," where τ_j (τ_j = $25, $50, $100, or $150) represents the tax price posed to the ith respondent. Thus, we can only model the probability of a "Yes" vote as $\Pr(WTP_i \geq \tau_j)$ or $1 - \Pr(WTP_i < \tau_j)$. In the standard first-price model in which votes on only the tax price are obtained, a sample consists of two censored groups. The first of these groups, for which $\Pr(WTP_i \geq \tau_j)$, has WTP values that are censored over the interval $[\tau_j, \infty)$, while the second group, for which $\Pr(WTP_i < \tau_j)$, is censored over the interval $(-\infty, \tau_j)$. The information from the follow-up question is used to limit the WTP probability interval for "No" voters to

$\Pr(0 < WTP_i < \tau_j)$, and therefore our data are censored over $(0, \tau_j)$ rather than $(-\infty, \tau_j)$, with additional information on an uncensored subgroup of respondents (i.e., those who vote such that $WTP = 0$).

The additional information obtained through the follow-up question can be used to refine the estimated distribution of willingness to pay. Voting patterns of respondents can be broken out accordingly: (*a*) respondents who vote "No" on the tax price and state zero WTP in the follow-up question fall into group I_1; (*b*) respondents who vote "No" on the tax price but would be willing to pay some positive amount fall into group I_2; and (*c*) those who vote "Yes" on the tax price fall into group I_3.

The resulting log-likelihood function is given by

$$\text{(1)} \qquad \mathrm{Ln}\,\mathrm{L} = \sum_{i\in I_1} \ln \frac{1}{\sigma}\,\phi\left(\frac{-\mathbf{x}_i\beta}{\sigma}\right) + \sum_{i\in I_2} \ln\Phi\left(\frac{\tau_j - \mathbf{x}_i\beta}{\sigma}\right) + \sum_{i\in I_3} \ln\Phi\left(\frac{\mathbf{x}_i\beta - \tau_j}{\sigma}\right),$$

where ϕ and Φ represent the probability distribution function (pdf) and cumulative distribution function (cdf) of the normal distribution, respectively; τ_j is once again the tax price posed to an individual; $\mathbf{x}_i$ represents a row vector of explanatory variables for the *i*th respondent; β is a column vector of parameters to be estimated; and σ is the standard error.

The model represented by (1) is called the partially censored model (PCM), because one point of the distribution corresponding to individuals with zero WTP (I_1) is not censored. The results of this model are later compared to those of the censored probit, which is referred to as the fully censored model (FCM). The log-likelihood function for the FCM is identical to equation (1), except the first summation term for I_1 is dropped.

The model described above is estimated to examine factors contributing to WTP. Included in the model are variables to control for attitudes, such as beliefs about the impact of agriculture on environmental quality, as well as socioeconomic and demographic variables and a variable used to provide the basis for an econometric scope test. Table 4 lists the variables and their definitions, and provides descriptive statistics.

Discussion

The results of the econometric estimation discussed here are presented in table 5, under the heading "Partially Censored Model." The effective sample size used in the estimation was reduced from 828 to 762 because of item nonresponse across explanatory variables. Overall, the parameter estimates of the partially censored model are statistically significant, and the estimate for *ABATE_LVL* is positive and significant. The positive sign of *ABATE_LVL* suggests WTP increases with program benefits. This result can be taken as a validation of the survey design, i.e., information was conveyed in such a way that respondents were sensitive to levels of benefits provided.

As pointed out by Cameron and James, parameter estimates from censored logit and probit models can be loosely interpreted as representing the marginal contribution of each factor to WTP. An analogous interpretation applies to the model in its partially censored form. The overall marginal contribution of the 20% abatement level includes the impact of the interaction terms of *ABATE_LVL* with *BLV_TECH* and *FARM* (denoted by *RB* and *RF*, respectively, in table 4). To estimate the impact, WTP was predicted twice using the econometric model—once with the variable *HI_ABATE* set at 0

Table 4. Descriptive Statistics and Definitions of Variables Used in the Analysis

Variable Name	Description	Mean	Std. Error
ABATE_LVL	Abatement level (0 = 10%, 1 = 20%)	0.51	0.50
AG_POL	Believe ag practices result in nonpoint pollution (0 = No, 1 = Yes)	0.68	0.47
AG_BIO	Believe ag practices reduce biodiversity (0 = No, 1 = Yes)	0.69	0.46
BLV_TECH	Technology can be used to achieve a cleaner environment (0 = No, 1 = Yes)	0.79	0.40
FARM	Respondent is farm resident (0 = No, 1 = Yes)	0.09	0.29
ENV_GOAL	Protection of environment/prevention of pollution is very important (0 = No, 1 = Yes)	0.59	0.49
WORK	Respondent is employed (0 = No, 1 = Yes)	0.61	0.49
HI_ED	Respondent education level is Associate Degree or higher (0 = No, 1 = Yes)	0.17	0.38
CONTR	Respondent contributed to environmental cause in last year (0 = No, 1 = Yes)	0.24	0.43
MALE	Respondent is male (0 = No, 1 = Yes)	0.35	0.48
RB	Interaction term, *ABATE_LVL* * *BLV_TECH*	0.40	0.49
RF	Interaction term, *ABATE_LVL* * *FARM*	0.05	0.22
COST	Tax Price ($25, $50, $100, $150)	81.33	48.14
HOW_VOTE	Response to referendum (0 = "No" vote, 1 = "Yes" vote)	0.63	0.48
PAY_ANY_TX	Respondent not WTP proposed tax, but WTP some positive amount (0 = No, 1 = Yes)	0.04	0.20

Note: Sample size is 762, reflecting item nonresponse for variables used in the estimation.

Table 5. Estimation Results (dependent variable = *Willingness to Pay*)

	Partially Censored Model			Fully Censored Model		
Variable	Estimate	Std. Error	χ^2	Estimate	Std. Error	χ^2
Intercept	8.74	14.87	0.34	-253.91*	138.39	3.37
ABATE_LVL	36.23**	17.04	4.95	167.31*	97.83	2.92
AG_POL	29.41***	9.37	12.94	133.56**	62.21	4.61
AG_BIO	22.93**	9.33	6.19	88.40*	49.44	3.20
BLV_TECH	57.48***	13.91	16.27	249.07**	110.57	5.07
FARM	15.27	24.49	0.53	84.99	107.06	0.63
ENV_GOAL	29.82***	8.66	13.88	136.25**	60.50	5.07
WORK	16.12*	8.70	5.46	69.15	44.93	2.46
HI_ED	-19.04*	11.52	2.46	-60.95	46.15	1.33
CONTR	17.24*	10.49	3.89	85.95	53.33	2.60
MALE	-21.70**	8.82	7.45	-93.92*	50.59	3.45
RB	-31.37*	19.27	2.73	-140.90	100.16	1.98
RF	-68.34**	30.16	5.39	-334.43*	174.30	3.68
σ	94.09	4.47		360.85	131.47	
	Log likelihood = -1,946.89 Likelihood-ratio test $\chi^2_{[13]}$ = 110.45***			Log likelihood = -449.68 Likelihood-ratio test $\chi^2_{[13]}$ = 97.01***		

Notes: Single, double, and triple asterisks (*) denote significance at 90%, 95%, and 99%, respectively. Sample size is 762, reflecting item nonresponse for variables used in the estimation.

for each respondent, and once with *HI_ABATE* set at 1. The difference between the two WTP estimates was taken for each individual and averaged over the sample, yielding a marginal contribution of $5.10 for the *HI_ABATE* variable. The sample standard deviation for the combined variables was estimated at 23.01, suggesting the abatement level is insignificant in the model. However, a likelihood-ratio test can be used to judge whether the coefficients for *ABATE_LVL*, *RB*, and *RF* are jointly equal to zero. The hypothesis is rejected at the 95% level ($\chi^2_{[3]}$ = 8.24), implying scope is found jointly for these variables. Although the results on scope are mixed, they tend to solidify the results of the nonparametric scope test, and accord with the findings of Whitehead, Haab, and Huang.

Indicator variables for those respondents who believe agricultural practices cause pollution (*AG_POL*), for those who believe agricultural practices reduce biodiversity (*AG_BIO*), for those who believe a national policy goal of improving the environment is important (*ENV_GOAL*), and for those who had made a contribution to an environmental cause (*CONTR*) in the previous 12 months contribute positively to WTP. These results imply environmentally sensitive respondents have higher levels of support for the program than others.

The variable observed to contribute most to WTP (as measured by the marginal WTP increase of $57.48) is the attitudinal variable *BLV_TECH*. This outcome is not surprising, because voting for such a program should be consistent with the beliefs of those who claim technology can be used to improve the environment. It is interesting, however, that *RB* has a negative effect on WTP, which may mean those who believe in technology will vote for the program regardless of the level of nonpoint pollution abatement. The combined marginal effect for *BLV_TECH* and *RB*, estimated using econometric predictions, is $41.51 (standard error = 15.69), so impact of the belief in technology is still the largest of any variable in the model even when the negative sign of *RB* is accounted for.

The parameter estimate of *FARM* is not significant (table 5), but the estimate of *RF* indicates farm residents have a significantly lower marginal WTP for the higher abatement level. This finding suggests farmers may perceive that the marginal cost to them of achieving the higher (20%) abatement level would exceed the marginal benefit. In addition, producers may feel that a 20% level of abatement would either be too expensive to achieve, or an unrealistic target. However, there may be another explanation. Bosch, Cook, and Fuglie report, although farmers are concerned with water quality, they tend not to believe their own farm contributes to the problem. Similarly, Lichtenberg and Lessley found that producers perceived water quality problems at the state level to be worse than for their own land. Thus, farmers may not understand how small amounts of nonpoint pollution at local levels can collectively accumulate to create large-scale water quality problems.

Of the other variables, male respondents (*MALE*) are willing to pay less than female respondents. There is no expectation for males, and this result may not be comparable to surveys in other geographic regions. Those who are employed either full or part time (*WORK*) have higher WTP, which is consistent with ability to pay. In contrast, the WTP of those with the highest education level (*HI_ED*) is $19.04 less than average, which is possibly inconsistent with expectations about ability to pay.[14] However, a similar result has been found in studies of pesticide-free and organic foods.

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[14] Education was used as a proxy for income, due to high item nonresponse for income (13.3%). Furthermore, a likelihood-ratio test based on the subset of the sample responding to the income question showed that a model including only education was superior to a model using only income (99% significance level).

In table 5, the results of the partially censored probit model (PCM) represented by equation (1) are compared to the results of the fully censored probit model (FCM). Model selection cannot be based on the log-likelihood functions, because the two models involve a data transformation in terms of censoring intervals. In both models, the likelihood-ratio test for joint significance of the parameter estimates is significant at the 99+% level. However, parameter estimates for the PCM are more precise than those of the FCM, as indicated by the χ^2 statistics.

The information gained by inclusion of a follow-up question asking if a respondent who votes "No" is willing to pay anything appears to be significant. In the PCM, the mean WTP generated using noncensored values when $WTP = 0$ is \$114.98, whereas the mean WTP estimate using the FCM (as in Cameron and James) is \$216.25. Thus, the mean WTP predicted by the PCM is 137% higher than that of the nonparametric estimate of \$48.46, while the FCM estimate is 346% higher than the nonparametric estimate.

Figure 1 plots estimated WTP from the partially and fully censored models for each individual in the survey. As observed from this graph, WTP estimates from the partially censored model demonstrate considerably less variability in the range of estimates and, perhaps more importantly, relatively few individual estimates fall outside the range of the bid vector (\$0–\$150) as compared to the fully censored model. Specifically, 11.8% of WTP estimates in the FCM model fall below \$0, and 67.6% fall above \$150. In comparison, only 0.5% of the PCM estimates fall below and 18.5% fall above the \$0–\$150 bounds. Based on this result, not only are the parameter estimates more precise in the PCM, but the WTP estimates are as well.

In addition, differences in the magnitude of the parameter estimates and WTP estimates between the PCM and FCM suggest the PCM may be superior. For example, if one interprets the coefficient estimates as marginal effects, the FCM places about 4.5 times the weight on certain factors (e.g., *ABATE_LVL*) than does the PCM, while placing nearly nine times the weight on other factors (e.g., *RF*). The difference in relative contribution between the two models can lead to qualitatively different inferences. From a policy perspective, misplaced emphasis of such factors may be misleading. In a benefit-cost analysis, WTP from the FCM has the potential to seriously overestimate program benefits in relation to WTP from the PCM. Haab and McConnell provide a comprehensive study of different survey design and econometric specifications to estimate referendum data, distinguishing between the stage in which parameters are estimated and the stage in which WTP is calculated. In keeping with the criteria set forth by Haab and McConnell, it appears our model performs well both in precision of estimated parameters and WTP.

One intuitive explanation of why WTP estimated by the PCM is lower than the corresponding estimate by the fully censored model is that the FCM may overestimate the probability of a "No" vote being greater than zero; such an effect may be exacerbated when the percentage of "Yes" votes in a survey is high. It is worth noting that in our sample, of those voting "No" on the WTP question, only 41.6% would be willing to pay any positive amount. Because the sample probability of "Yes" votes based on univariate analysis ranged from 0.61 to 0.71, depending on tax price, it is possible the FCM overestimates the probability of a "Yes" vote for censored WTP values.

A second possibility in explaining why WTP estimated by the PCM is lower than from the FCM is related to potential bias introduced by follow-up questions, or by the inclusion of a quasi-open-ended question allowing for zero stated WTP. With respect to double-bounded follow-up questions, Carson, Flores, and Meade, and Alberini, Kanninen, and Carson caution that the existence of second prices may cause preferences to shift. Results

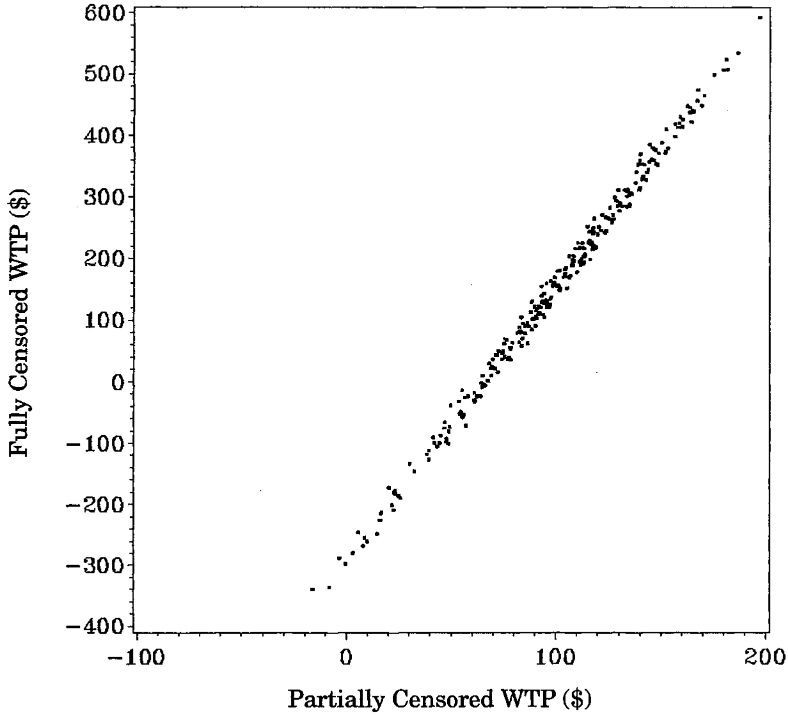

Figure 1. Plot of predicted WTP from fully censored and partially censored probit models

obtained by Cameron and Quiggin indicate WTP estimates using follow-up questions are lower than those based on first-price referenda only. Cameron and Quiggin suggest the reason for these results is that the observed probability of a "Yes" on the follow-up is lower than what would be expected based on the probabilities generated by the first vote. Furthermore, downward bias can be introduced by the follow-up question because the possibility of zero WTP allows for "protest" votes (Green et al.).

To address these questions, we investigated the zero WTP votes, and compared them to the entire sample. Among the "No" votes, the findings revealed males had a significantly higher percentage of zero WTP than would be expected by the probabilities in the first price (64.5% vs. 42.4%). Likewise, individuals whose follow-up responses revealed an unwillingness to pay more taxes were overrepresented. However, financial factors also may have played an important role. Specifically, the percentage of those unemployed in the zero WTP group was much higher than those voting "No" in the overall sample (54% vs. 33%), suggesting some of the zero WTP responses may have been due to inability to pay. Nonetheless, there does appear to be evidence pointing to the existence of a substantial portion of protest votes.

To determine the potential effect of protest votes on the model outcome, 59 respondents from the zero WTP group were randomly assigned to the category $0 < WTP < Tax\ Price$, whereby the percentage of zero WTP among the "No" votes was just slightly higher than the first-price distribution of "No" votes. The partially censored model was rerun, with results showing mean WTP increases by only about $4 to $118.24. Once again, the estimated WTP stayed primarily within the bounds of the bid vector, demonstrating that even when protest votes are taken into account, the partially censored model may be superior to the fully censored model.

Conclusions

The findings of this study have important implications for programs to promote environmentally friendly agricultural practices. In particular, even though Mississippi is poor and rural, our study reveals significant public support exists for a program to reduce nonpoint pollution from agriculture. The potential viability of a program to subsidize VRT adoption within Mississippi is also illustrated by these results.

Mississippi had 5,947,311 crop acres under cultivation in 1998. If it is assumed one VRT unit can effectively service 1,000 acres per year, the total cost to implement this program in Mississippi would range between $59 million and $119 million, depending on the assumed price of the technology. In 1998, 1,066,156 individual tax returns were filed in Mississippi (Mississippi State Tax Commission), resulting in estimated tax revenues for the VRT adoption program ranging from $52 million (based on the nonparametric mean WTP) and $122 million (based on mean WTP from the econometric model). Thus, potential tax revenues should be sufficient to cover a substantial portion of the program's cost. Because a subsidy would not be expected to cover 100% of adoption costs, our analysis suggests public WTP could provide a sizable incentive for producers to adopt precision application technology.

Mississippi is a rural state and residents may be more inclined to support programs perceived to benefit farmers. However, "helping farmers" did not appear to be the primary motivation for voting for the program as measured by the survey instrument. Nevertheless, these results should be viewed with caution, as they may not generalize to other regions of the country.

We note one caveat with respect to any subsidy program for adopting technology. Although environmental benefits may be gained at the intensive margin, increased production at the extensive margin may actually increase overall pollution (National Research Council), so that subsidies alone might be counterproductive. However, Khanna and Zilberman found site-specific management practices may not be profitable if combined with a tax. Based on these considerations, we would therefore expect a subsidy program to be most successful as part of a package of policies including standards such as total maximum daily loads (TMDLs).

From a methodological perspective, the value of adding a follow-up question for zero WTP in the survey instrument and of econometrically modeling zero WTP as noncensored responses is illustrated. The mean WTP estimates derived from this method are nearly half those obtained from the censored probit model, and are closer in magnitude to WTP measures derived from nonparametric methods. Furthermore, there are efficiency gains in the parameter estimates of the econometric model and, more importantly, in the predicted WTP estimates. Another important finding is that the type of follow-up question used to generate the model does not cause significant bias from shifting of preferences or from protest votes, implying the PCM method can improve WTP estimates while maintaining the desirable incentive compatibility characteristics of single-price referendum CV.

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